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Application of the HDR imaging in vehicles' video tracking systems

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ABSTRACT
Video systems are used in Intelligent Transportation Systems for vehicles' tracking. Cameras typically used in these systems are characterized by relatively low dynamic range which is only a fragment of the dynamic range of the human eye. In order to adapt to the lighting conditions the cameras feature dynamic changes of the gain and exposure. For vehicles there is a very wide range of the observed brightness of details because of the variety of vehicles' colors and the presence of elements reflecting light in different ways, as well as changing lighting conditions. This means that even if the camera is able to capture the relevant dynamic range, there is a restriction of the distinguishability of details, which is essential in the process of detecting the location of vehicles. The use of HDR imaging techniques based on various exposures helps to increase the dynamic range and improves the accuracy of vehicles' positions estimation.

KEYWORDS: vehicles' tracking, High Dynamic Range images, Intelligent Transportation Systems

1. Introduction

Intelligent Transportation Systems (ITS) utilize various types of road sensors for the estimation of the traffic parameters [1]. The use of the video cameras is probably the most interesting approach, since they allow measuring some parameters, which are unavailable using some other technologies. The cameras are usually installed at a given height over a road, such that a relatively large area can be monitored. Typical places for such installations are buildings or dedicated pylons, especially outside urban areas.

One of the main advantages of the video cameras is the ability to measure many traffic parameters, even in different fragments of the road, using only a single camera. Nevertheless, some digital image processing and analysis or pattern recognition algorithms have to be applied for this purpose. Furthermore, due to the installation over the road, there are no problems related with possible surface damage during the installation, in contrast to some road built-in sensors (e.g. inductive loop, optical pressure sensors etc.) [1,2].

The use of the video cameras in the ITS has also some disadvantages, especially high sensitivity on the weather conditions. Using the near infra-red (IR) cameras the camera's sensitivity can be increased (usually the IR filter is not used, so the camera has high sensitivity for the near IR but the visible light range is also handled). The cameras working for medium and far infra-red range (thermographic) have much greater scope but presently their prices are also very high. The full color video cameras working in the visible light range allow also the estimation of the vehicles' colors and the increase of the separation between the vehicles on the obtained images. Probably, the dominating trend in the ITS applications will be related to the multi-spectral analysis, since each range can be characterized by its unique advantages.

A serious limitation of the video cameras is the dynamic range of the acquired intensity of light. The expected range is the same, or even wider, as the Human Visual System (HVS), but the image interpreted by a human brain is strongly processed. Presently available technologies, both

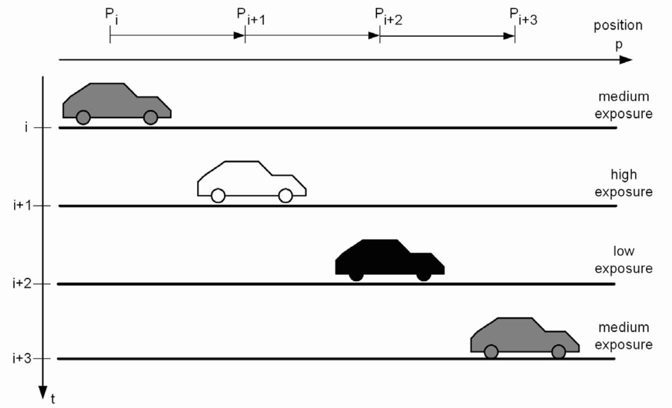

Fig. 1. Idea of the synchronization of the measurements obtained for various exposure time.
Source: [own work]

digital cameras and photographic film, are is just a taste of the possibilities of people.

A typical image acquired by a digital camera is usually overexposed or underexposed (often both problems occur on the same image). This phenomenon is especially evident in the ITS applications where a fragment of the background may be dark and opaque, similarly as some of the vehicles, while some others may be highly reflective (metallic). The dynamic range of the camera working in the sunshine should be very high, but unfortunately this cannot be obtained even using modern cameras.

There are some cameras with nonlinear acquisition characteristics for the CCD [3-5] but at the moment such equipment is rather experimental than commonly available.

A possible solution, also for existing infrastructure, can be the High Dynamic Range (HDR) image acquisition [6]. Such images can be acquired during the process of multiple acquisition of images for different exposures followed by their fusion into a single image with a wider dynamic range using digital image processing algorithms. This operation can be performed using a series of video frames acquiring using the same camera, using several cameras [7] or using the CCD with various sensitivity of its pixels.

2. HDR imaging for the ITS

The development of the HDR technology occurs in two directions. The first one is related to the processing of the HDR images and the second one is their conversion to the Low Dynamic Range (LDR) images (tonemapping), necessary for the display using the currently available monitors.

The most relevant aspect for the ITS applications is the image processing allowing e.g. better acquisition of the image for further processing e.g. recognition of the vehicle's type.

In this paper the low cost solution based on the existing systems with controllable exposure time is analyzed. The varying exposure can be used for the cameras equipped with an electronic shutter. Such solution is effective, since it does not require any moving parts working continuously inside the camera.

The approach proposed in the paper is based on the various exposure time for each acquired frame, tracking of the vehicles for each of them and the fusion of the obtained images in order to obtain the HDR image. In the consequence, both tracking and the HDR imaging is obtained.

Commonly used algorithms of the fusion of complete images utilize the alignment methods for the matching of the consecutive frames, especially when they are obtained from the moving camera without a tripod. Assuming the static camera, such additional alignment is unnecessary. Nevertheless, the ITS applications require the use of a modified alignment algorithm. The camera and the scene (treated as the background) are static, but the fragments of the images representing the vehicles are located at various positions on the images acquired for the various exposure times.

The first step of the algorithm, which is applied independently for the image pairs, is the background estimation leading to the result image transformed such that it contains only the static elements. The simplest approach is the long-time averaging of frames [8]. The vehicles visible at various locations on the image are treaded as noise. Since their colors and brightness are different, the average tends to the background image. Better results can be obtained for the algorithms detecting the differences of the images, allowing faster convergence and more adequate results.

Using the difference between the current frame and the estimated background with the same exposure time, the differential image can be obtained. Using the thresholding the membership of the pixel to the vehicle (above the threshold) or the background (below the threshold) can be specified. The area of the image containing the vehicle is usually called a blob due to its specific shape.

For a large number of vehicles the kinematics estimation algorithms should be applied in order to determine the track for each of them. For the simplification, a single vehicle observed from a side is assumed in the paper. For the identification of the method's possibilities the synthetic analysis is performed, but for the real images obtained from the camera, some other observation angles can also be used.

The tracking of multiple vehicles is possible using the Multiple Hypothesis Testing (MHT) algorithm [9]. For the tracking of vehicles various kinematics estimators can be used e.g. Kalman filter [10,11], which allow the prediction of the current position based on the previous measurements, so the obtained result can be compared to the nearest blob location in the current measurement. The difference between the prediction and the location is then used for the filter's update.

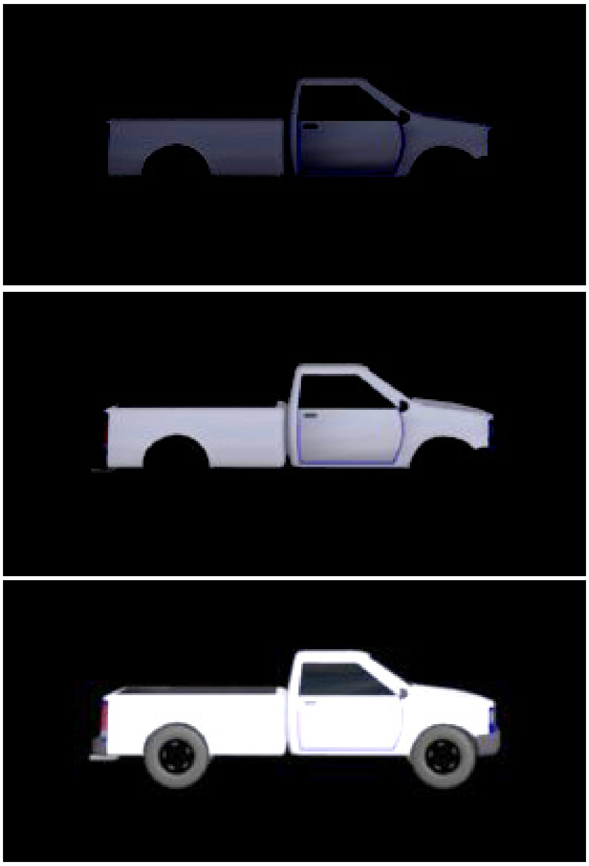

Fig. 2. Example images obtained for various exposure time.
Source: [own work]

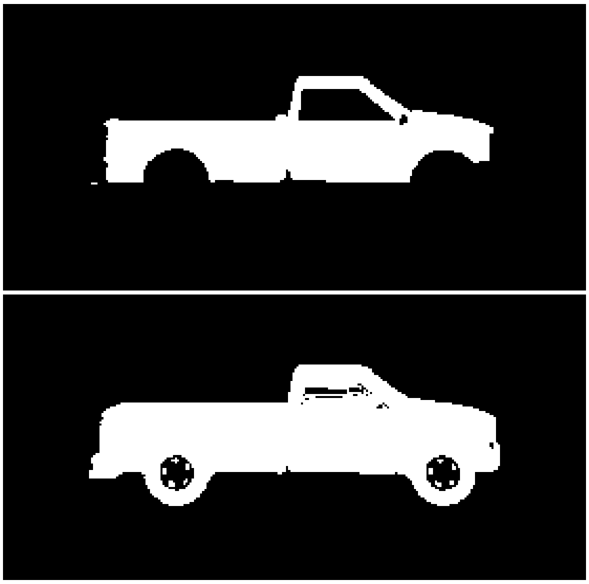

Fig. 3. Mask images determining the pixels belonging to the specified exposure time (the first one contains all the pixels).
Source: [own work]

The tracking process can utilize all the measurements obtained using various exposure time. In the cases, when the blob is not detected using the thresholding the reason may be related to e.g. too short exposure time, only the result of prediction is used as the location estimation. Due to the synchronization of the measurements obtained for various exposure time with the respective exposure values, the tracking can be continued even without the presence of the blob in several frames.

In order to determine the HDR image of the vehicle, which can be useful e.g. for the classification purposes, the fusion of the images acquired for different exposure time is necessary.

For the proper alignment of the consecutive frames, the correlation of the images obtained for different exposure time should be calculated, what in not always an easy task. For all images a common range of luminance, present in two frames is necessary. For three different exposure times, the middle frame should contain the common range at its both range boundaries. The resulting image is then combined using the intermediate images.

There are many algorithms of image fusion used in the HDR imaging. One of the most convenient ones is the Mean Threshold Alignment (MTA) [12,13], because of its high processing speed and relatively good results. The idea of the method is based on the grayscale image processing so the first step is the conversion from the RGB image performed for all pixels as:

$$Y = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B \quad (1)$$

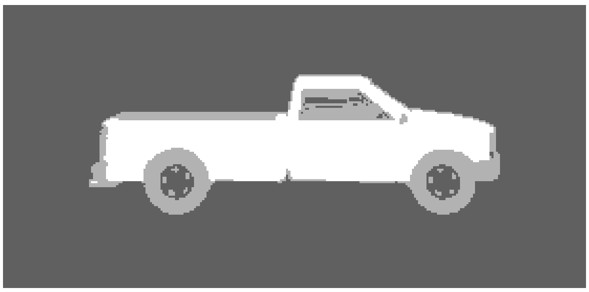

Fig. 4. Cumulative visualization of the masks.
Source: [own work]

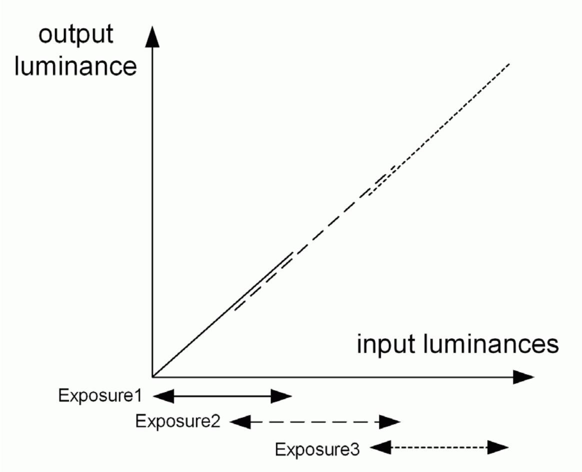

**Fig. 5. Illustration of the camera response curve.
Source: [own work]**

For each *j*-th image the median value (MED_j) is then calculated used further for thresholding

$$B_j(x,y) = \begin{cases} 0 : Y_j(x,y) \le MED_j \\ 1 : Y_j(x,y) \ge MED_j \end{cases} \quad (2)$$

where $B_j(x,y)$ is the binary value of a specified pixel.

The pair of images with a common fragment of the dynamic range can be compared using the XOR operation:

$$E_j = \sum_{x,y} B_j(x,y) \oplus B_{j+1}(x,y) \quad (3)$$

and the matching process corresponds to the minimization by searching:

$$\min \sum_{x,y} B_j(x,y) \oplus B_{j+1}(x+\Delta x, y+\Delta y) \quad (4)$$

where Δx and Δy denote the relative translation of both binary images. For small images the translation by one pixel can be used in order to check all the combinations, but for larger ones some optimization methods can be useful.

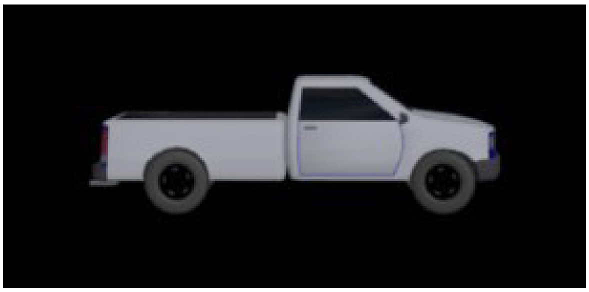

**Fig. 6. The final effect with additional tonemapping applied for printing purposes.
Source: [own work]**

The images obtained after matching should be further processed using the camera response curve, which should be determined for each exposure time.

For the cameras used in the ITS the luminance calibration can be performed for each exposure time, so the luminance transform process is simplified, in contrast to the unknown exposure time or unknown luminance curves (not always linear). Nevertheless, such curve can also be determined for a given camera using a calibration table.

After the transformation of the image series into a single HDR image, some further algorithms of image processing, analysis and recognition can be applied.

3. Conclusions and future work

The utilization of the HDR imaging for the video based vehicle tracking can be a promising direction of research related to the development of the machine vision algorithms for the ITS applications. Presented preliminary

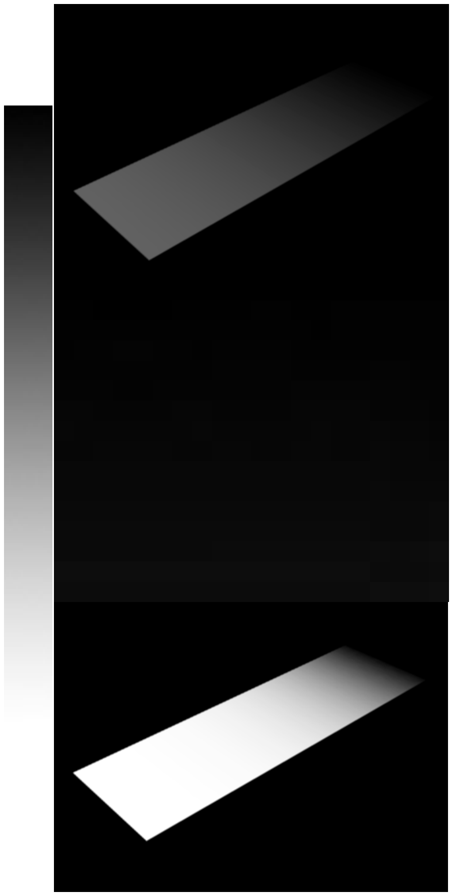

**Fig. 7. An example synthetic grayscale gradient for various exposure time.
Source: [own work]**

results obtained for some synthetic images seem to be helpful for some other algorithms used on the Intelligent Transportation Systems, especially related to the statistical traffic analysis as well as e.g. register license plate's numbers recognition in various light conditions.

Nevertheless, matching the images obtained for the varying light conditions may be troublesome in some situations and some more sophisticated algorithms should be used. The application of them, also for some real images acquired from the video cameras, is planned as a part of our future work.

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